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Research on Agricultural Total Production Factors in the Bohai Bay Area Based on Agricultural Data from 2011 to 2020

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Abstract: This paper studied the total factor productivity (TFP) of agriculture in the Bohai Rim region. The agricultural TFP showed the dependence of agricultural development on chemical fertilizers, pesticides, labor, science, technology, etc. By coordinating the inputs of various production factors, production efficiency can be improved, reducing the over-reliance on chemical fertilizers and pesticides and achieving the development and sustainability of agriculture. In this study, the sectional data of three provinces (Shandong, Hebei, and Liaoning) and two cities (Beijing and Tianjin) in the Bohai Rim region of China from 2011 to 2020 were collected, and the envelope analysis was performed on the collected data using the Malmquist index model. The results showed that the TFP of agriculture in the Bohai Rim region was greater than one, and agriculture was generally well-developed. Regionally, the agricultural productivity in Shandong Province was generally lower than in other provinces and cities. In addition, the scale efficiency was the most important factor restricting agricultural TFP in the Bohai Rim region, indicating that there was still room to improve investment in the agricultural production scale. Based on the analysis results, suggestions were made for sustainable and high-quality development of agriculture.

Keywords: total factor productivity; utilization of agricultural resources; sustainable development; agricultural development; sustainable agriculture

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1. Introduction

As the primary industry of the country, agriculture is an important industrial sector in the national economy. It uses land resources as production objects to support the construction and development of the national economy. The Bohai Rim region includes Beijing, Tianjin, Hebei Province, Liaoning Province, and Shandong Province [1]. The Bohai Rim region is one of the most active agricultural regions in northern China and a major planting area for soybeans and corn, with huge development potential. The Bohai Rim region has become the most important economic development region in China, second only to the Yangtze River Delta and Pearl River Delta [2]. However, the unsustainable development of agriculture in the Bohai Rim region is becoming increasingly evident. It is mainly reflected in the excessive use of fertilizers and pesticides by smallholder farmers in pursuit of higher agricultural productivity [3], causing economic waste and agricultural non-point source pollution [4]. Moreover, farmers have insufficient understanding of the promotion of agricultural machinery and the dissemination of agricultural technology, resulting in a low sense of happiness during the farming process. The deterioration of the ecological environment and the low sense of happiness among rural farmers hinder the achievement of sustainable development goals [5]. Despite the Chinese government and scholars having repeatedly called for attention to rural development, the development of agriculture still lags behind [6,7]. How to improve agricultural production efficiency while improving sustainability is crucial for agricultural development.

There are two main methods for agricultural development: one is to increase the resource elements of agricultural development, such as expanding arable land, increasing fertilizers and pesticides, and increasing agricultural labor force. Another method is to improve the coordination of various agricultural factors, increase and adjust various agricultural production factors to improve production efficiency. The core of agricultural development is to improve the efficiency of agricultural production. There are many evaluation methods for production efficiency, including traditional three-factor evaluation methods (the three elements generally include land, capital, and labor) [8], and multi-factor comprehensive input-output evaluation methods [9]. However, these evaluation methods lack comprehensiveness. The evaluation method for agricultural production efficiency has gradually developed to appropriately reflect this through the total factor productivity (TFP). The National Quality Agriculture Revitalization Strategic Plan (2018–2022) issued by the Ministry of Agriculture and Rural Affairs of China emphasizes the need to improve agricultural total factor productivity to achieve high-quality revitalization of agriculture. The agricultural TFP is an important indicator for agricultural economic development, and it is increasingly being used by scholars to study agricultural development [10]. The TFP shows the dependence of agricultural development on production factors such as fertilizer, pesticide, labor force, science, and technology. It also reveals the efficiency of input and output of various factors in agricultural production. In order to reduce the over-dependence of agriculture on fertilizers and pesticides, it is necessary to comprehensively coordinate the input of various production factors. From the perspective of environmental ecology and agricultural sustainability, studying the TFP in agriculture and finding the direction to coordinate various production factors are of great practical significance for the sustainable development of agriculture in the Bohai Rim region.

2. Literature Review

The total factor productivity (TFP) was first proposed by Tinbergen in 1942 [11]. On this basis, Robert put forward the concept of Solow Surplus [12]. Solow Surplus suggested that the input growth rate was deducted from the output growth rate under constant returns to scale, and the remaining items represented the rate of technological progress. Hulten believed that the Solow remainder should be considered as another more complete statement of TFP [13]. In addition to the change in technological progress, the Solow remainder also reflects the impact of measurement errors, missing variables, random factors, etc. These were the earliest and relatively complete concepts of agricultural TFP.

Because of the importance of agriculture in developing countries, research on improving agricultural production has attracted much attention. Several researchers have conducted in-depth studies on the growth of agricultural productivity from different perspectives. Farrell pioneered the study of production efficiency and proposed a method for measuring agricultural production efficiency: he supplemented and considered inputs in agricultural production other than labor [14]. Subsequently, Kawagoe et al. estimated the overall agricultural production function using the cross-border data of 1960, 1970, and 1980. The agricultural productivity between developed and less developed countries was compared, and the results showed that the returns of developing countries were increasing [15]. Sanzidur and Ruhul used the Fare-Primont index to study the agricultural TFP index of 17 regions in Bangladesh in 1948 [16]. The results revealed that the sustained growth of TFP was mainly driven by technological progress. Matthew studied the relationship between public investment in agricultural R and D, productivity growth, and economic benefits in the United States from 1949 to 2002 [17]. Barath and Ferto studied the changes in relative and decomposition productivity of European agriculture from 2004 to 2013. The results showed that the TFP in Europe decreased slightly, with significant differences among member countries [18]. Sanzidur and Basanta analyzed the technical efficiency of agriculture in Bangladesh through a stochastic frontier analysis. The average technical efficiency score of rice production was high, reaching the level of 90% [19].

In recent years, research on the TFP in Chinese agriculture has also received extensive attention. Xu and Tian studied the TFP of China's agricultural sector from 1950 to 2008, with an annual growth rate of 2.03% [20]. Many researchers found that agricultural production in China faced low technical efficiencies and pointed out that agricultural productivity can be improved with higher technical efficiency [21,22]. Based on Chinese provincial data from 2001 to 2012, Yin and Wang found an upward trend in technical efficiency [23]. Zeng et al. used the stochastic frontier approach (SFA) method to study the impact of land consolidation measures implemented in China on agricultural technology efficiency [24]. The results showed that land integration promoted the transfer of land tenure and improved non-agricultural employment, thus improving the agricultural employment level of producers. Shen et al. analyzed the changes in agricultural TFP in China from 1997 to 2015 using the Luenberger-Hicks-Moorsteen TFP index. It was found that TFP growth in China varied over time and space, and public investment in agricultural R and D had positive economic returns. In recent years, due to global attention to the issue of "Carbon Emissions Reduction and Carbon Peaking", scholars have begun to consider the issue of agricultural total factor productivity under environmental constraints, and have proposed the concept of green agricultural total factor productivity [4]. It revealed the sustainable growth beyond input factors under environmental pressure, and also incorporated issues such as agricultural non-point source pollution and carbon emissions into the measurement indicators of agricultural total factor productivity.

The previous studies on agricultural TFP were relatively complete. However, most studies focused on the country or a single province, and the research on a cross-province region (e.g., the Bohai Rim region) was relatively limited. Therefore, this study uses the Malmquist index model to calculate and analyze the agricultural TFP of the Bohai Rim region from 2011 to 2020. The findings are expected to be a reference for the high-quality agricultural development in the Bohai Rim region and provide guidance for regional development.

3. Materials and Methods

3.1. Study Area

The Bohai Sea is a medium-sized gulf with an area of approximately 77,000 km^2, a coastline of 3800 km, and an average water depth of 18 m. it is located on the east coast of mainland China. The map of the Bohai Rim is shown in Figure 1.

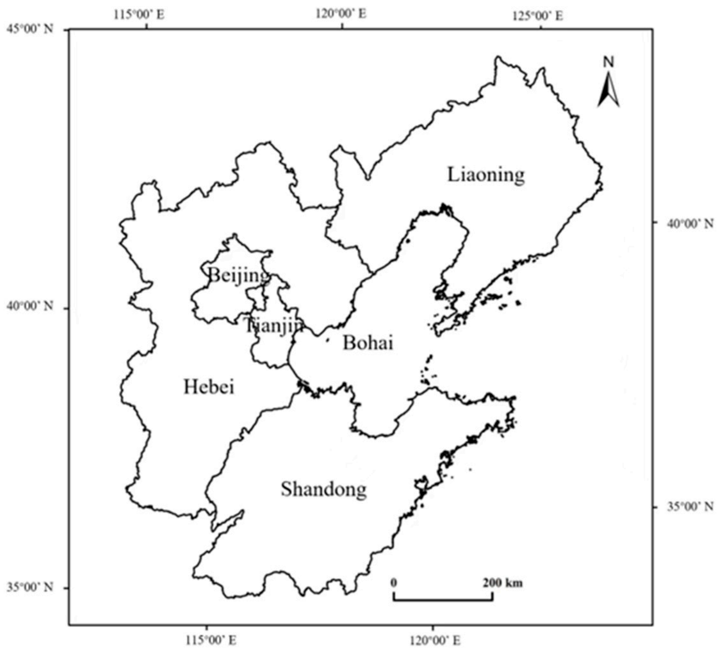


Figure 1. Map of Bohai Rim.

The politically significant Bohai Rim region includes seven provinces and cities, including Beijing and Tianjin, as well as Hebei Province, Liaoning Province, Shandong Province, Shanxi Province, and the central region of Inner Mongolia. The geographical significance of the Bohai Rim region includes three provinces and cities directly connected to the Bohai Sea, including Beijing, Tianjin, Hebei, Shandong, and Liaoning provinces. This study used the geographical significance of the Bohai Rim region, including three provinces (Liaoning, Hebei, and Shandong) and two cities (Tianjin and Beijing), covering an area of approximately 1,280,000 km^2. The map of the Bohai Rim is shown in Figure 1.

According to the 2022 China Rural Statistical Yearbook's statistics on summer grain planting and yield in various provinces, the national summer grain planting area in 2022 was 265,300 square kilometers. The summer grain planting area in Shandong and Hebei provinces has reached 62,763 square kilometers, accounting for 23.66% of the national total. Among them, Hebei Province and Shandong Province are both important agricultural provinces, producing large amounts of agricultural products such as soybeans and corn.

3.2. Model Selection and Variable Determination

3.2.1. Malmquist Index Model

Malmquist was first proposed by Malmquist in 1953 to analyze the process of consumption. The DEA method was used by Rolf and Daniel to calculate the Malmquist index, which compensated the static section of the DEA model [25]. The Malmquist index indicates the change in degree of TFP from period t to (t + 1). A Trpch higher than 1 indicates an increase in productivity; a Trpch lower than 1 indicates a decrease in productivity; a Trpch equal to 1 indicates unchanged productivity [26]. The specific equation is as follows:

$$Trpch(x_{t+1}, y_{t+1}, x_t, y_t) = \frac{E(x_{t+1}, y_{t+1})}{E(x_t, y_t)} \tag{1}$$

The change of technical efficiency from t to (t + 1) is

$$Effect = \frac{E_{t+1}(x_{t+1}, y_{t+1})}{E_t(x_t, y_t)} \tag{2}$$

The technical change from t to (t + 1) can be expressed by Equations (3) and (4):

$$Tech = \frac{\frac{E(x_{t+1}, y_{t+1})}{E_{t+1}(x_{t+1}, y_{t+1})}}{\frac{E(x_t, y_t)}{E_t(x_t, y_t)}} \tag{3}$$

$$Tech = \frac{E(x_{t+1}, y_{t+1})}{E_{t+1}(x_{t+1}, y_{t+1})} \times \frac{E_t(x_t, y_t)}{E(x_t, y_t)} \tag{4}$$

Equation (1) can be expressed as follows based on the above equations:

$$\begin{aligned} Trpch(x_{t+1}, y_{t+1}, x_t, y_t) &= \frac{E(x_{t+1}, y_{t+1})}{E(x_t, y_t)} \\ &= \frac{\frac{E(x_{t+1}, y_{t+1})}{E_{t+1}(x_{t+1}, y_{t+1})}}{E_t(x_t, y_t)} \times \left(\frac{E(x_{t+1}, y_{t+1})}{E_{t+1}(x_{t+1}, y_{t+1})} \times \frac{E_t(x_t, y_t)}{E(x_t, y_t)} \right) \\ &= Effect \times Tech \end{aligned} \tag{5}$$

When the return to scale is variable, Equation (5) can also be decomposed into Equation (6):

$$Trpch = Tech \times Pech \times Sech \tag{6}$$

In the above equations, *Tech* represents the technical level change index, *Pech* represents the pure technical efficiency change index, and *Sech* represents the scale efficiency change index [27].

3.2.2. Indicator Selection

Three provinces and two cities in the Bohai Bay area were selected as the research scope. According to previous studies [28,29], the panel data of agricultural production were selected to calculate the TFP of agriculture in the Bohai Bay area. In terms of indicator selection, we have also increased chemical inputs such as pesticides and fertilizers, taking into account the efficiency of green and sustainable agricultural development. The relative independence of five input indicators, two output indicators, and similar indicators was tested using SPSS. The indicator system constructed in this study is shown in Table 1.

Table 1. Indicators of agricultural TFP efficiency.

First Level Indicator	Second Level Indicator	Third Level Indicator
Input indicator	Human resources investment	The population engaged in agriculture, forestry, animal husbandry, and fishery
	Capital investment	Agriculture, forestry, and water conservancy affairs
	Scientific and technological investment	Total power of agricultural machinery
	Land input	The total planting area of crops
	Chemical input	Fertilizer application rate
Output indicator	Living standard	Per capita net income of rural households
	Agricultural development level	The total output value of agriculture, forestry, animal husbandry, and fishery

3.3. Data Sources

The above data were all obtained from provincial statistical yearbooks (Hebei Statistical Yearbook, Shandong Statistical Yearbook, Liaoning Statistical Yearbook, etc.), urban statistical yearbooks, and the China Rural Statistical Yearbooks. The time span is ten years, and the scope is 2011–2020.

4. Results and Discussion

This study used DEAP2.1 and the Malmquist index model to analyze the agricultural TFP of five provincial administrative regions in three provinces and two cities around the Bohai Sea. The research results coordinated various elements of agricultural development in the Bohai Rim region and provided ways to improve the efficiency of agricultural development. We hope that these studies can be helpful for the sustainable development of agriculture in the Bohai Rim region. The empirical results are shown in Tables 2 and 3.

Table 2. Malmquist index and decomposition of agricultural production in the Bohai Bay area in 2011–2020.

Year	Effch	Tech	Pech	Sech	Trpch
2011–2012	0.993	1.124	1.000	0.993	1.116
2012–2013	1.008	1.104	1.000	1.008	1.113
2013–2014	0.998	1.056	1.000	0.998	1.054
2014–2015	1.004	1.048	1.000	1.004	1.053
2015–2016	1.05	0.934	1.000	1.05	0.98
2016–2017	0.994	1.057	1.000	0.994	1.051
2017–2018	1.005	1.084	1.000	1.005	1.089
2018–2019	0.994	1.071	1.000	0.994	1.065
2019–2020	1.013	1.06	1.000	1.013	1.076
Mean	1.007	1.060	1.000	1.007	1.066

Table 3. Malmquist index and decomposition of agricultural production areas in the Bohai Bay area from 2011 to 2020.

Area	Effch	Tech	Pech	Sech	Trpch
Beijing	1.000	1.064	1.000	1.000	1.064
Tianjin	1.000	1.135	1.000	1.000	1.135
Hebei	1.020	1.025	1.000	1.020	1.046
Liaoning	1.000	1.048	1.000	1.000	1.048
Shandong	1.012	1.024	1.000	1.012	1.036
Mean	1.006	1.059	1.000	1.006	1.066

It can be seen from Table 2 that from 2011 to 2020, only the TFP of agriculture in the Bohai Rim region is less than one in 2015–2016. The Trpch index is greater than one in the other periods. The TFP of agriculture in 2011–2012 is the highest, reaching 1.116. The mean value of the agricultural TFP index in the Bohai Rim region from 2011 to 2020 is 1.066, indicating that the agricultural TFP in the Bohai Rim region had an overall upward trend in the past decade, with an average annual increase of 6.6%. Moreover, Table 2 shows that the mean value of the change index (Effch) of agricultural production technology efficiency in the Bohai Rim region from 2011 to 2020 is 1.007 (>1). It indicates that the Effch in the Bohai Rim region showed an upward trend from 2011 to 2020, with a mean annual increase value of 0.7%. From the perspective of each time interval, the Effch index slightly fluctuates around one. In the four time periods of 2011–2012, 2013–2014, 2016–2017, and 2018–2019, the Effch is less than one.

The changes in agricultural technology level in the Bohai Rim region can be interpreted from Table 2. During 2011–2020, the average value of Tech is 1.060, indicating an increasing level of agricultural technology in the Bohai Rim region, with an average annual growth of 6.0%. However, the difference in Tech is large, with a maximum value of 1.124 in 2011–2012 and a minimum value of 0.934 in 2015–2016. According to the analysis of the pure technical efficiency change index (Pech) in Table 2, the Pech remains unchanged at 1.0 in 2011–2020. The agricultural Sech in the Bohai Rim region shows a relatively slow growth with a mean value of 1.007 from 2011 to 2020.

Based on the above analysis, it can be found that the synchronization rate of Effch and Sech is high, while that of Effch, Tech, and Pech was not high, and the opposite was true in some years. This result suggests that the transformation and use of agricultural technology in the Bohai Rim region is still problematic, and technology transformation is inefficient. In summary, the efficiency of agricultural production in the Bohai Rim region was steadily improving. However, there was still a problem of low scale efficiency, indicating that the content of agricultural technology needs to be improved. Moreover, there was still a shortage of senior agricultural technicians, and overall planning of inputs to agricultural production was relatively lacking, reflecting the weakness of agricultural production planning.

The Malmquist index model was used to analyze the dynamic efficiency of agricultural production in five provincial administrative regions around the Bohai Sea. The results are shown in Table 3. The mean agricultural production of each region around the Bohai Sea is 1.066, with an average annual growth of 6.6%. The Trpch of Beijing, Tianjin, Hebei, Liaoning, and Shandong is greater than one, indicating a steady increase in agricultural production efficiency. The Trpch value in Tianjin is 1.135, and the lowest Trpch is 1.036 in Shandong Province. Further decomposition of the Trpch shows that the Effch of Beijing, Tianjin, and Liaoning is all one, indicating that the technical efficiency of these three regions was generally stable. The Effch of Hebei and Shandong is greater than one. From 2011 to 2020, Hebei's average annual growth rate was 2.0%, and Shandong's average annual growth rate was 1.2%. The Tech of the five regions is significantly greater than one, suggesting that the agricultural productivity in the Bohai Rim region is mainly driven by improved agricultural technology. The Effch, Pech, and Sech are also greater than or equal to one, suggesting that these aspects also facilitated the overall development of agriculture in the Bohai Rim region. The development state was stable and had a high quality.

Figure 2 displays the agricultural production efficiency of the regions around the Bohai Sea.

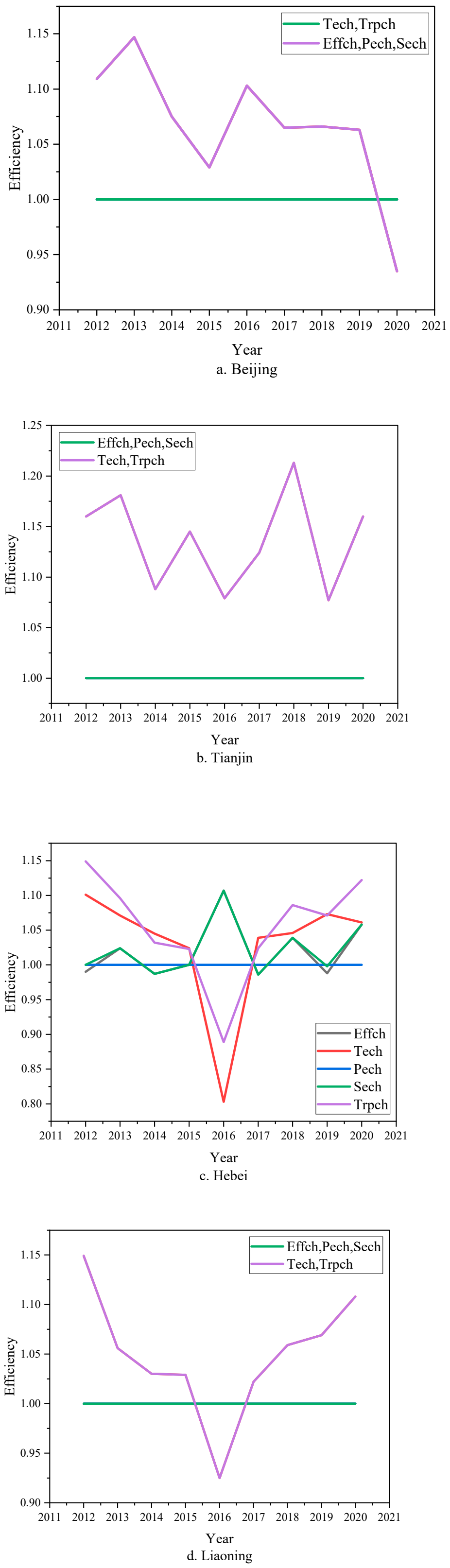
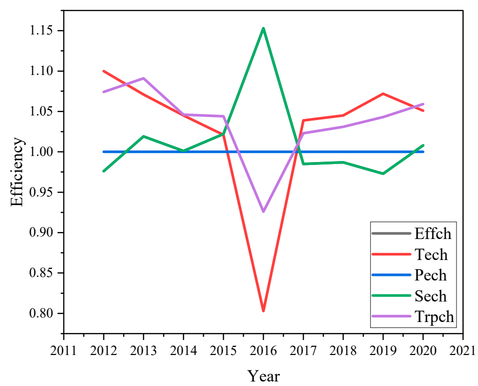
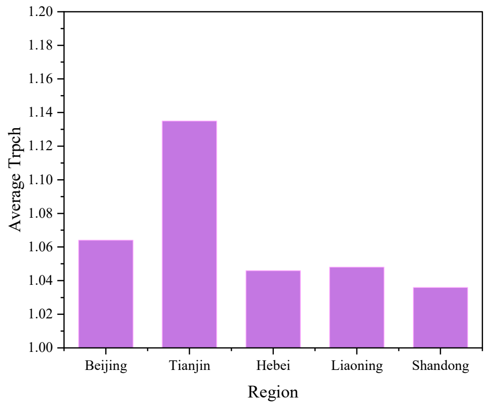


Figure 2. *Cont.*



e. Shandong



f. Reginal average

Figure 2. Results of agricultural TFP analysis in the Bohai Rim region (**a**–**e**) are the results of TFP in Beijing, Tianjin, Hebei, Liaoning, and Shandong provinces for ten years, respectively. Among them, the indicators of Beijing, Tianjin, and Liaoning overlap, which can be found in the legend. Additionally, (**f**) is the comparison of the average productivity of each administrative region in the Bohai Rim region from 2011 to 2020).

The agricultural productivity of Beijing during 2011–2020 is one, which is relatively stable. The Effch, Tech, and Sech are all greater than one in 2011–2019 but less than one in 2020. The overall agricultural productivity of Tianjin is greater than one, with slight fluctuations. The Effch, Pech, and Sech are relatively stable from 2011 to 2020, with an efficiency value of one. The agricultural productivity of Hebei Province is less than one in 2016, and the Trpch is greater than one in other years during the research period. The variation in Trpch in Liaoning Province and Shandong Province is similar to that in Hebei Province. The agricultural productivity is less than one in 2016, while that in other years is greater than one. It might be caused by the widespread natural disasters in China in 2016, affecting 8531.4 hectares of crops and leading to the loss of 1297.3 hectares. In addition, extreme and severe convective weather frequently occurred in 2016, and the affected area of crops was 2.908 million hectares, of which 268.8 thousand hectares were lost. Therefore, agricultural technology should be enhanced to improve the protection ability and reduce agricultural disasters under extreme weather conditions.

To sum up, we found that the Trpch index in the Bohai Rim region is greater than one. It indicates that the overall agricultural production efficiency in the Bohai Rim region has an upward trend. However, there are significant regional differences between the three provinces and two cities in the Bohai Rim region. Some provinces still have problems such as low technology conversion rates and unreasonable allocation of agricultural resources. There is significant room for further improving agricultural productivity by adjusting various production factors in agriculture.

5. Conclusions

According to the dynamic efficiency analysis of the Malmquist index model, the Trpch index in the Bohai Rim region is greater than one in 2011–2020, indicating a rising trend of the overall agricultural production efficiency in the Bohai Rim region. However, there are still regional differences, low technology conversion rates, and unreasonable allocation of agricultural resources. From the regional perspective, the agricultural productivity of Shandong Province is the lowest in the research period. This result indicates that the agricultural progress in the three provinces is slow from 2011 to 2020, and there is still much room for improvement. Overall, the agricultural productivity of the five provincial administrative regions is greater than one, indicating favorable development and an outstanding technical level.

Based on the above findings and the goal of sustainable development of agriculture in the Bohai Rim region, the following suggestions are proposed:

First, the integrity of agricultural development in the Bohai Rim region should be improved. The area around the Bohai Sea includes three provinces (Shandong, Hebei, and Liaoning) and two cities (Beijing and Tianjin). These regions have different agricultural bases and development objectives. And they are independently managed by different provincial agricultural departments, with a considerable degree of independence. Therefore, all regions should communicate and cooperate to promote the coordinated development of regional agriculture.

Second, investment should be increased in agricultural science and technology to promote agricultural technology development. Based on the analysis results, the agricultural technology level in the Bohai Rim region has developed to a relatively good and stable level, and the technology is no longer a shortboard restricting agricultural development. However, as the region keeps advancing in science and technology but continues to lose the rural population, agricultural, cultural, and scientific talents should be actively introduced and cultivated. Furthermore, excellent varieties and green fertilizers should be developed to promote the green development of agriculture. Talents in agricultural science should also be introduced to ensure the transformation and development of agricultural scientific and technological achievements.

Third, large-scale planting and the security system should be promoted. According to the comparative analysis, scale efficiency is the most promising factor for agricultural development. This is mainly due to the temporary cultivation status in the Bohai Rim region, especially in Shandong and Hebei, which is mostly small-scale scattered planting by small farmers. There are significant difficulties in achieving collective and mechanized cultivation of small-scale land. Therefore, efforts can be made on large-scale land planting policies to guide the large-scale use of land. In addition, innovative investment models and industrial services can facilitate agricultural development, ensuring efficient and sustainable development of cultivated land resources in the Bohai Rim region.

The practical significance of this study is to provide guidance for the agricultural development status in the Bohai Rim region, enabling it to better achieve sustainable and high-quality development. On the one hand, by reasonably allocating various agricultural resources, the efficiency of agricultural production can be further improved; On the other hand, empirical analysis has proven that the limiting factor for agricultural development in the Bohai Rim region is not chemical input (i.e., it can reduce farmers' dependence on fertilizers and pesticides). It is of great significance in the development of agricultural economy and the protection of ecological environment. In addition, it also provides direction for the government's policies to regulate agricultural development. The specific practical methods can be guided by government policies and subsidies for large-scale land use. According to our research results, such agricultural development measures can improve the sustainability of agricultural development in the Bohai Rim region.

Of course, this research has certain limitations. On the one hand, this study did not consider the impact of natural resource factors (such as rainfall, annual average temperature, annual temperature difference, etc.) on agricultural development. On the other hand, the data level used in this study is provincial data, which is not precise enough for the situation of prefecture-level cities.

The future researchers can enrich research indicators by comprehensively considering other factors that affect agricultural development, such as rainfall, annual average temperature, annual temperature difference, etc. In addition, the source of research data can be expanded from provincial data to prefecture-level cities, making the research more detailed and reliable.

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